

Predicting the Radiation Environments for Future Space Exploration Missions

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Problem

The natural space radiations pose a serious health risk to humans and contribute to failure rates for electronics during space missions. The risks must be predicted accurately for future space exploration missions.

→ A practical approach of expected radiation environment

Approach

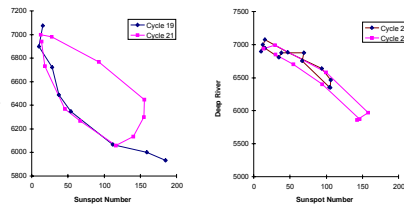
- Sunspot number is well correlated with many observable space quantities and represents variation in the space radiation environment. A solar cycle statistical model⁽¹⁻³⁾ was developed based on the accumulating cycle sunspot data.
- A predictive model for GCR temporal dependence^(4,5) represented by GCR deceleration potential (ϕ) was derived from GCR flux and ground-based Climax neutron monitor rate measurements over the last four decades.

→ Prediction of Radiation Environments and Doses for Future Space Exploration Missions.

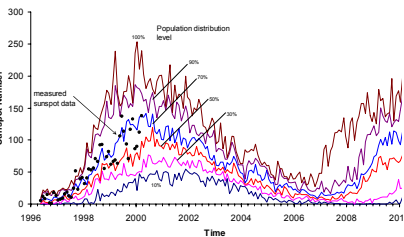
Solar Cycle Statistical Model and Projection of Space-Related Quantities

The interplanetary space radiation environment is affected by the degree of solar disturbance that is related to the number and types of sunspots in the solar surface. Using the monthly mean sunspot numbers of the numbered cycles (1755 to the present), a statistical model based on the accumulating historical cycle sunspot data has been developed to estimate future levels of solar cycle activity. Since the sunspot cycle affects the near-Earth environment, the data is coupled to space-related quantities, such as the GCR deceleration potential (ϕ) and the mean occurrence frequency of SPE, which are of interest in radiation protection.

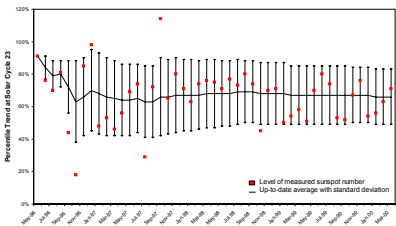
Correlation between Sunspot Number and Particle Fluence



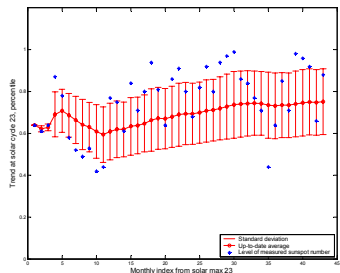
Measured Sunspot Data and Population Distributions of Odd Cycles



Population Group of Rising Phase of Cycle 23 (Cumulative Mean Value and Statistical Fluctuation)

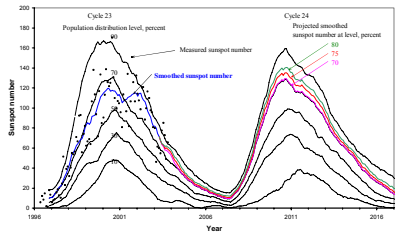


Population Group of Declining Phase of Cycle 23 (Cumulative Mean Value and Statistical Fluctuation)

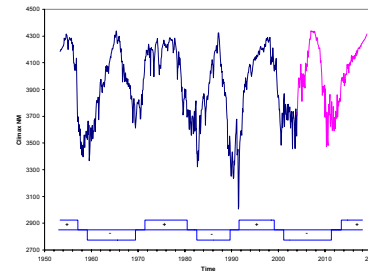


Projections of Solar Cycles 23 and 24

A basis for estimating of exposure in future space missions

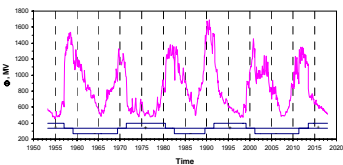


Climax Neutron Monitor Rate Measurements and Projection to Solar Cycles 23 and 24

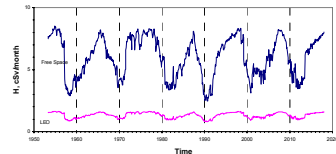


GCR Temporal Dependence

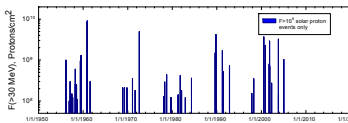
GCR Deceleration Potential



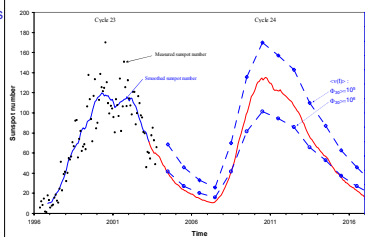
Point Dose Equivalents inside Spacecraft (5 g/cm² Al)



Large SPEs Occurrence



Projections of Cycles and Mean Occurrence Frequency of SPE



Measurements of Total Proton Fluence and Projections of Mean Occurrence Frequency of SPE

(in Year 2003)

| Particle Event | | $\Phi_p(\geq 30 \text{ MeV})$, p/cm² | Annual Mean Sunspots | Mean Occurrence Frequency of SPE per Year | |
|----------------|-------------|---------------------------------------|----------------------|---|-----------------------|
| Start | Peak | | | $\Phi_{10} \geq 10^6$ | $\Phi_{10} \geq 10^7$ |
| 5/28/23:35 | 5/29/15:30 | 1.10×10^6 | 63 | 4.0 | 6.7 |
| 5/31/00:40 | 5/31/06:45 | 1.95×10^6 | | | |
| 6/18/20:50 | 6/19/04:50 | 4.17×10^6 | | | |
| 10/26/18:25* | 10/26/22:35 | 3.25×10^6 | | | |
| 11/2/11:05* | 11/3/08:15 | 1.50×10^6 | | | |
| 11/4/22:25* | 11/5/06:00 | 1.87×10^6 | | | |
| 11/21/23:55 | 11/22/02:30 | 4.24×10^6 | | | |
| 12/2/15:05 | 12/2/17:30 | 7.33×10^6 | | | |

*For the combined SPE (Oct 26 – Nov 6, 2003):
 $\Phi_p(\geq 30 \text{ MeV}) = 3.42 \times 10^6 \text{ protons/cm}^2$

Summary

- A statistical model to predict future solar activity has been developed
 - Useful analysis tool for exploration mission design studies
- A temporal forecast of GCR has been derived from GCR flux and Climax neutron monitor rate measurements
- Future radiation environments are predicted represented by GCR deceleration potential (ϕ)
 - Point dose equivalent in interplanetary space is influenced by solar modulation by a factor of 3
 - Relationship between large SPE occurrence and ϕ is clearly shown
 - Future work: A probability model for predicting a simulated worst case SPE during an arbitrary design period is needed

References

- (1) J. W. Wilson, M. Y. Kim, J. L. Shinn, H. Tai, F. A. Cucinotta, G. D. Badhwar, F. F. Badavi, and W. Atwell, *Solar Cycle Variation and Application to the Space Radiation Environment*. NASA/TP-1999-209369, 1999.
- (2) M. Y. Kim and J. W. Wilson, *Examination of Solar Cycle Statistical Model and New Prediction of Solar Cycle 23*. NASA/TP-2000-210536, 2000.
- (3) M. Y. Kim, J. W. Wilson, and F. A. Cucinotta, *An Improved Solar Cycle Statistical Model for the Projection of Near Future Sunspot Cycles*. NASA/TP-2004-212070, 2004.
- (4) G. D. Badhwar, F. A. Cucinotta, and P. M. O'Neill, An Analysis of Interplanetary Space Radiation Exposure for Various Solar Cycles. *Radiat. Res.* **138**, 201-208 (1994).
- (5) G. D. Badhwar, The Radiation Environment in Low-Earth Orbit. *Radiat. Res.* **148**, S3-S10 (1997).